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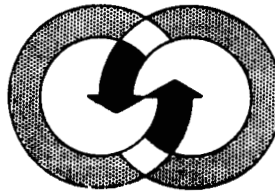
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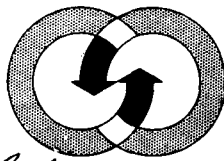
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EVALUATION OF INSULATED WIRE
FOR SPACE ENVIRONMENT

~~FINAL REPORT~~

(NASA CR --- ; Report Number 05132-4) OTS: (cover)

Date February 7, 1963

By

Richard H. Suess *and*

George R. Neff

7 Feb. 1963 55 p orig

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APPLIED RESEARCH DEVELOPMENT

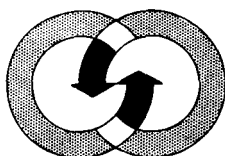
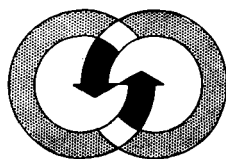


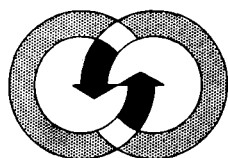
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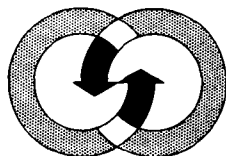
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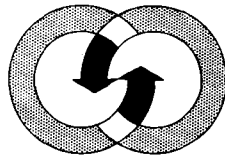
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ABSTRACT

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Six candidate conductor systems have been evaluated in a simulated hyper space environment. These included polyolefin, teflon, "H" film, polyvinyl fluoride, and polyimide insulation. The test results indicate that the teflon and polyimide systems performed the most satisfactorily in the test parameters used. However, some of the other conductors are not considered unacceptable but only questionable. Explanations of test methods, analysis of data, conclusions, and recommendations for possible future testing are included. *Author*



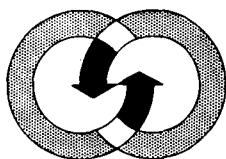
EVALUATION OF WIRE IN A SIMULATED SPACE ENVIRONMENT

INTRODUCTION

This program was instituted and developed with a dual purpose in mind. First and foremost is the evaluation and qualification of these particular wire types for use in the space environment. The second purpose is the evaluation of qualification parameters used, so that future test programs of this type may be conducted with a substantial reduction in time and cost. For this reason the report will be divided into several sections, separately discussing these purposes and finally combining the total of these findings for use in determining the necessity and extent of future test work.

Throughout this report the wires tested will be referred to by number in the order listed below.

1. Raychem Corporation - Rayolin N
RT22(19) U-O Black. Reel #1-4-28-62-1
2. Sonic Wire Sales - Extruded TFE Teflon
EXE-22-1934 White/Green-4PL-PO#M2-163611
3. Hitemp Wires Incorporated
VF-24-124 Polyvinyl Fluoride
4. Supernant Wires
"Suroc" FEP w/corona etched, bonded "ML" polyimide
5. Tensolite Wire Company
"UT" Ultra-thin emulsion dipped TFE
6. W. L. Gore
FEP Teflon with "H" Film, Teflon and "H" Film laminated
into tape and helically wrapped.



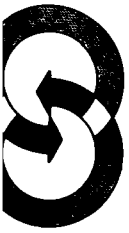
I. TEST METHODS

This section is concerned with the exact methods used by ARDEL CORPORATION for the evaluation of insulated wire samples for use in the space environment. The results of the testing and analysis of the data will appear in subsequent sections.

ABRASION TEST

A standard abrasion test device manufactured by Janco Corporation and supplied by the Jet Propulsion Laboratories is used for this test. The abrasion tape is 400 mesh aluminum oxide with electrically conductive strips spaced three inches apart. The wire to be tested is stretched taut under a one pound load. A four ounce weight is then placed on the wire at the point of contact with the abrasion tape.

The tape is then run along the point of contact with the wire until enough wire insulation has been worn away to allow the conductive strips to contact the bare conductor. The length of tape required to do this is a measure of the insulator abrasion resistance. A minimum of eight tests are made on each sample, each test at least three inches from the last and the wire is rotated 90° each time. A diagram of this apparatus appears in Figure 1.



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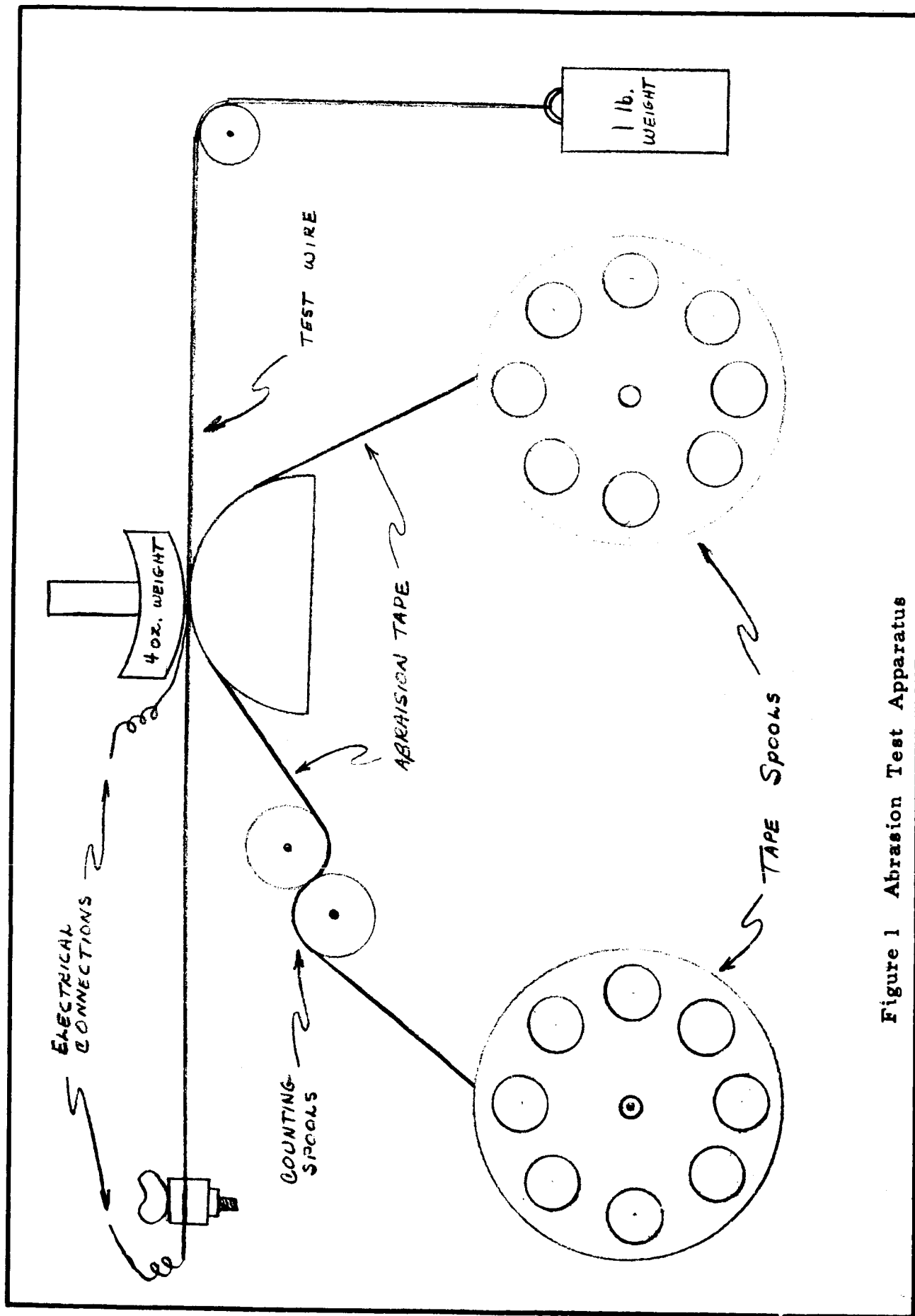
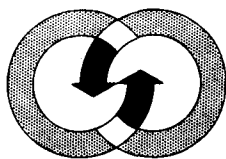


Figure 1 Abrasion Test Apparatus



FLEXURE TEST

The device used for measurement of wire flexure through a minimum radius bend was designed and fabricated by ARDEL CORPORATION and is pictured in Figure 2. The device is more easily explained by discussing its three component parts separately. First, the vacuum pumping system on the right of the picture is a 400 liter per second getter ion type pump capable of pumping the clean, dry baked-out system to 10^{-10} torr.

The chamber proper is a 304 series stainless steel cross with specially designed high vacuum flanges at the termination of each of the fingers of the cross. The lower end of the cross is joined to a Pyrex glass tube through a Kovar grade. The lower end of this tube is hidden in the picture by a dewar filled with liquid nitrogen.

Through the upper flanges, the actual flexure apparatus is inserted into the chamber and extends into the glass tube portion of the chamber. The sample is flexed by actuation of the brass bellows extending above the upper flange. A more detailed picture of the flexure apparatus within the Pyrex tube is seen in Figure 3.

The test of a typical sample is performed in the following manner:

A test specimen 7.5 inches in length with small hooks brazed on each end is mounted on the test fixture as shown in Figure 3 and the entire unit assembled. A roughing pump is connected to the system which

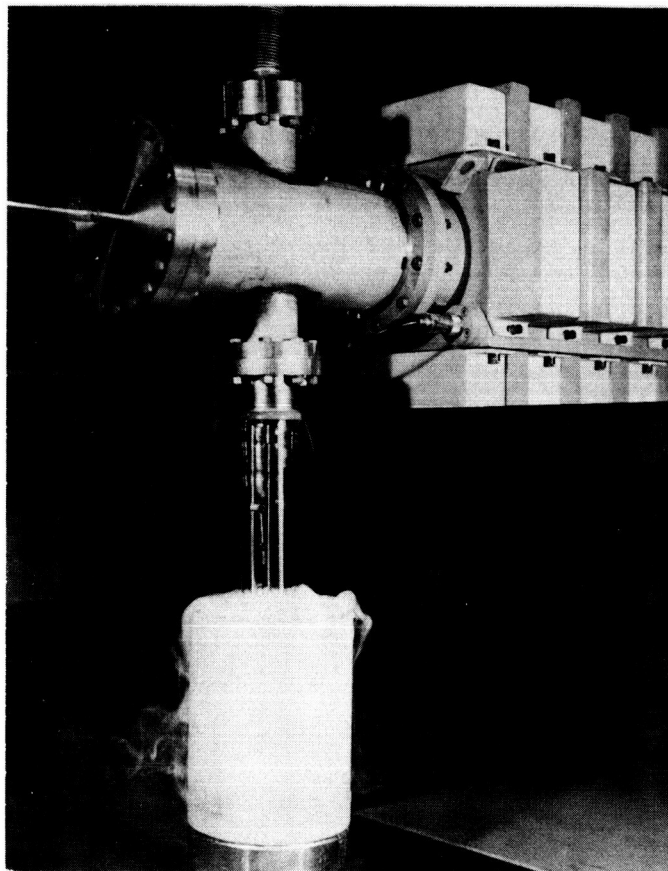
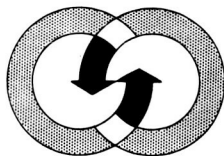


Figure 2

Flexure Apparatus

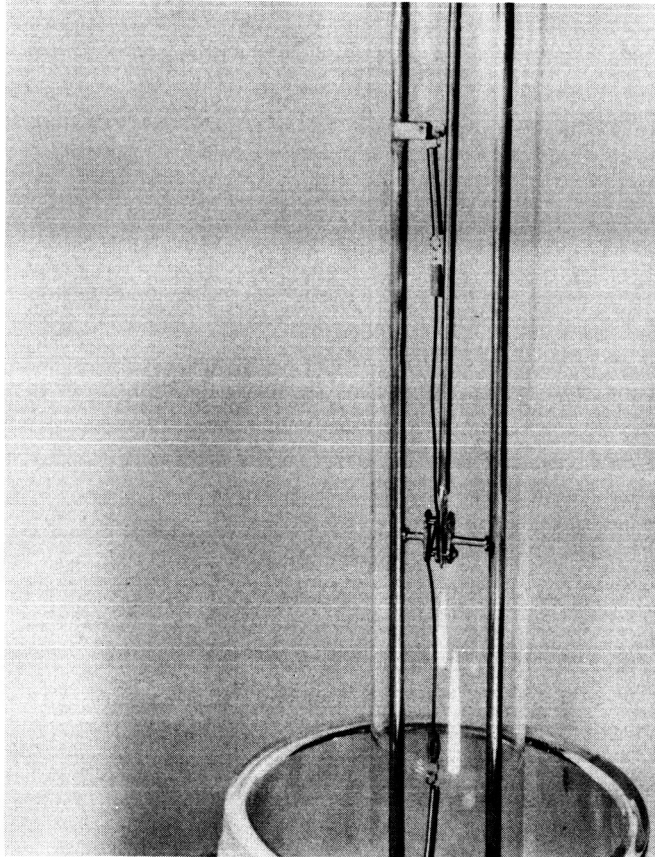
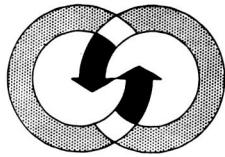
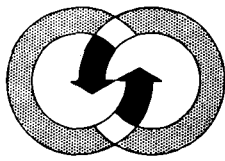


Figure 3

Detailed View of Flexure Device

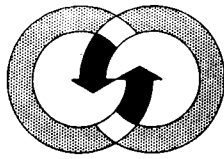


is evacuated to a pressure of approximately 1×10^{-4} torr. At this point the ion gettering pump is turned on and the roughing pump sealed from the system by standard glass blowing techniques. The system is then allowed to pump to approximately 10^{-9} torr or a pressure limited by the outgassing of the sample.

When the pressure has achieved its low point, a bath is placed around the glass portion of the chamber. This bath is filled with liquid nitrogen, dry ice-acetone or hot oil depending on the test temperature required. When the pressure has again reached its lowest point, the flexing of the wire is begun. The wire is flexed a total of one hundred times.

Upon removal from the chamber the wire is first examined visually for any irregularity. Immediately following this, the sample is measured dimensionally with a micrometer at several points along the wire. Any difference between the wire at the point of flex and along its length is carefully noted. Measurements of resistance and dielectric breakdown are made as a final check on the sample.

Dimensional measurements are reported as "in bend" and "out bend" which are both taken at the point of flexure. The former indicates the cold flow at the point of contact of the wire and test fixture while the latter is measured by rotating the wire ninety degrees and indicates distortion due to the pressure at the flex point.



VACUUM THERMAL TESTS

The vacuum thermal tests are performed on a system known as a "vacuum train". This train is composed of several exposure chambers (shown in Figure 4) connected to a vacuum pumping system through a Pyrex manifold. Each chamber may be isolated from the system by a ten millimeter bore Pyrex stopcock. The pumping system is composed of a series combination of two cryogenic traps backed by a .75 liter per second three stage mercury diffusion pump backed by a mechanical pump. Pressure measurement is made by an ion gauge connected to the manifold at the end opposite the pumping system.

Insulated wire specimens are exposed to the vacuum environment in a coiled five foot length as shown in Figure 4 . Also shown is the radiant heater used for temperatures above ambient and the dewars filled with liquid nitrogen for reduced temperature. The length of time that each specimen is exposed to vacuum has been set at ten days.

ULTRA VIOLET RADIATION TESTS

Samples to be irradiated with high intensity ultra violet light are first mounted on the fixture pictured in Figure 5 . The copper blocks upon which the samples sit are hollow and are cooled with water during test. The vacuum chamber with quartz window to allow passage of the ultra violet is picture in Figure 6. This chamber is then connected to

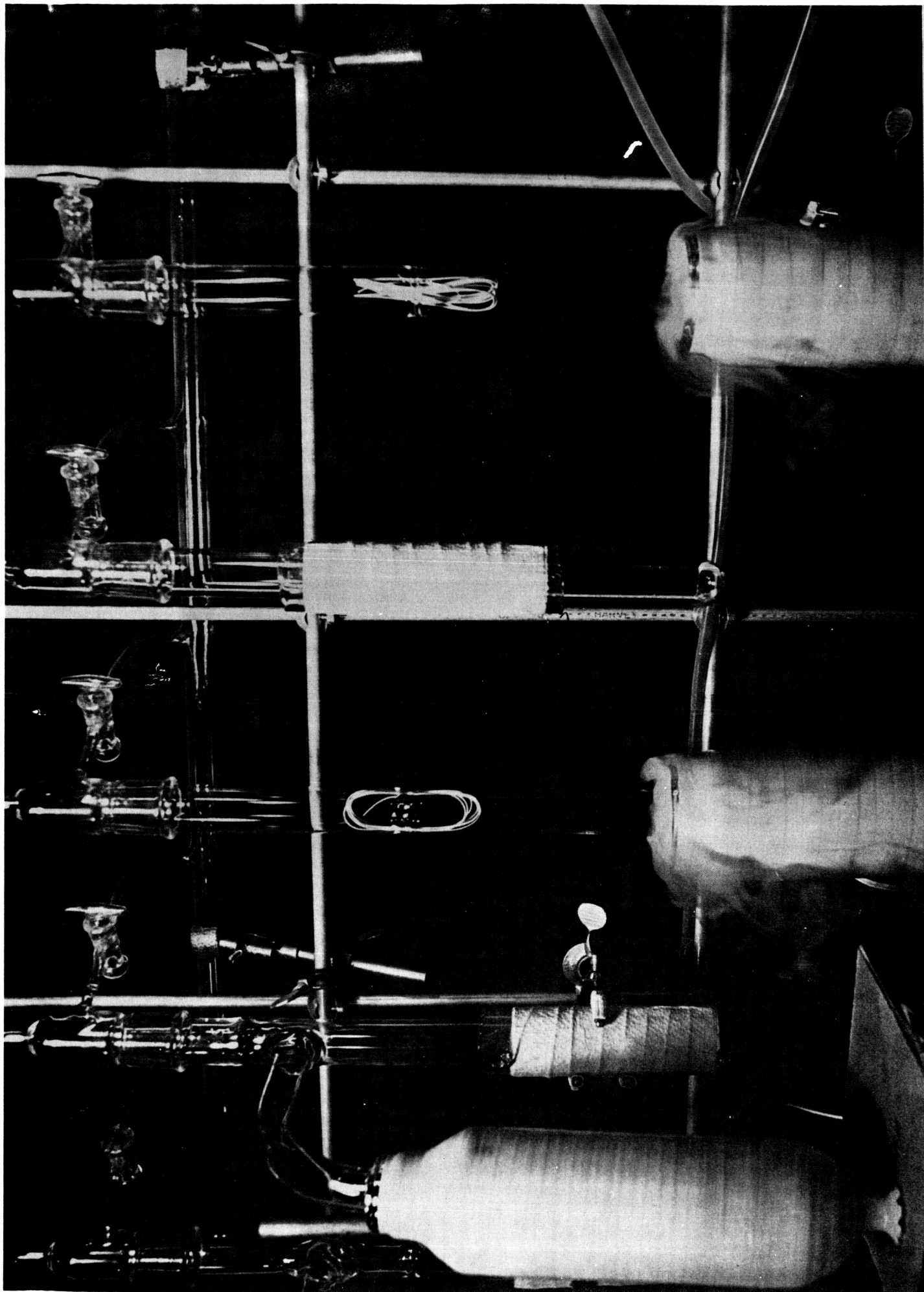


Figure 4 Vacuum Test Chamber

Figure 4

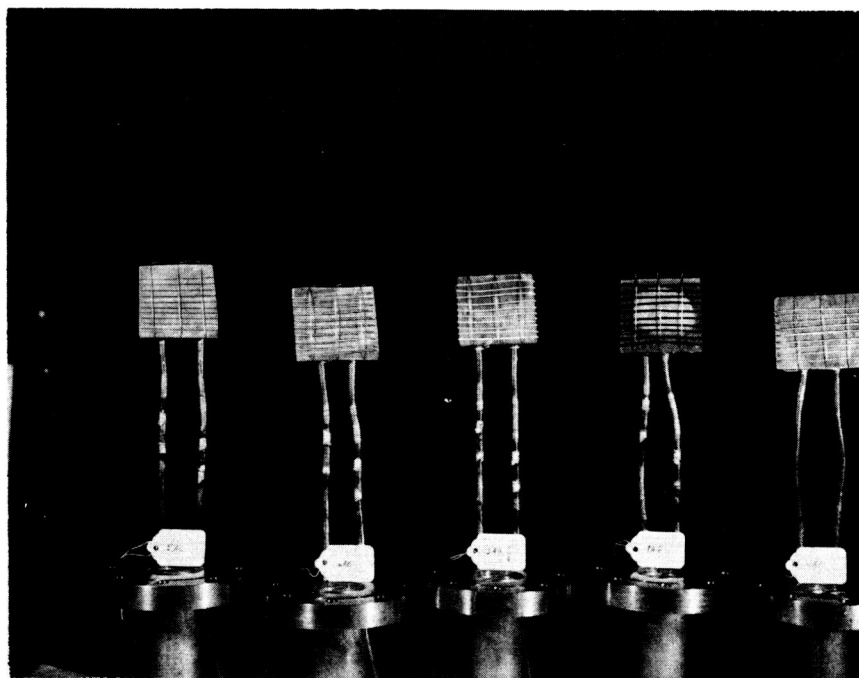
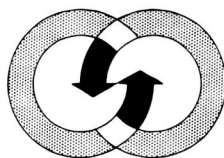


Figure 5

Ultraviolet Test Specimens Mounted On Copper Heat Sinks

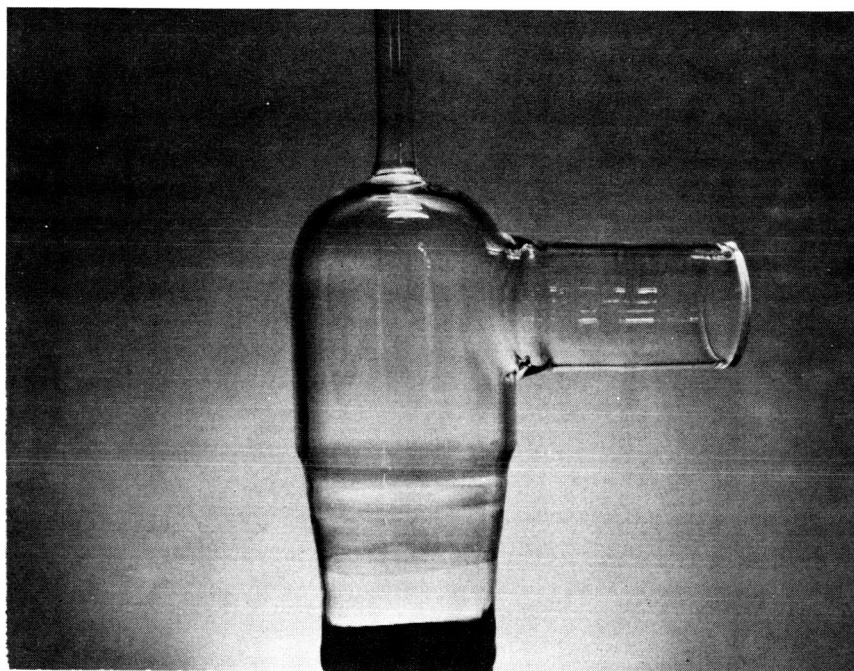
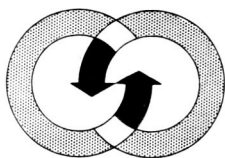
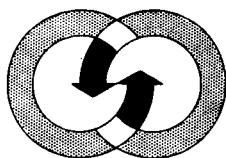


Figure 6

Ultra Violet Radiation Test Chamber



the apparatus holding the wire by means of a high vacuum, copper gasketed, knife edge flange. This entire system is in turn mounted on a 9 liter per second getter-ion type vacuum pump.

The ultra violet source is a General Electric high pressure mercury lamp designated as BH-6 cooled by an air jet.

The wire samples were exposed for 100 hours at 4.5 times normal solar radiation and a pressure of approximately 10^{-7} torr.

ELECTRICAL MEASUREMENTS

A test fixture has been constructed for use in all the electrical measurements to be made on the wire specimens. This fixture consists of glass fingers around which approximately five feet of wire is wound with the wire ends extending above the fixture. The apparatus is entirely immersed in mercury which acts as one electrode. The two conductor ends act as the other electrode. A guard circuit is provided by means of a copper plate under the mercury container and shielded connecting wire, both of which are grounded. A picture of this apparatus appears in Figure 7.

The procedures followed for each test are listed below together with the equipment used for testing.

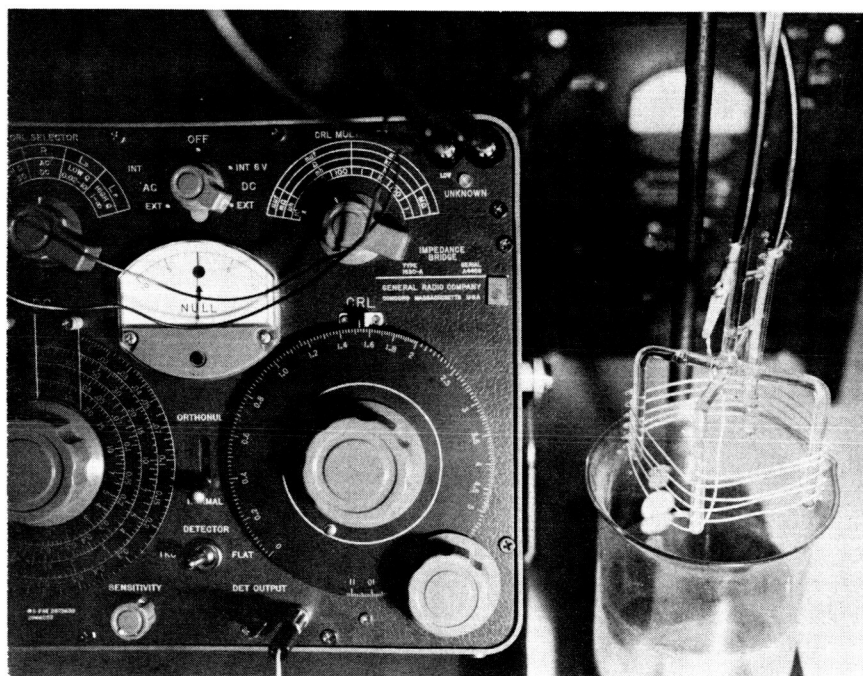
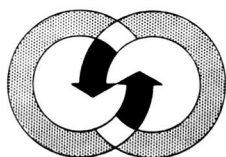
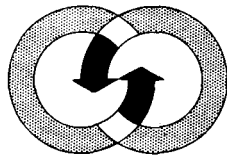


Figure 7

Apparatus for Electrical Measurements



DIELECTRIC STRENGTH

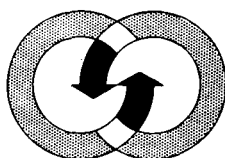
Test Procedure: A potential of 7500 volts A. C. RMS, 60 cps, was applied, at a rate not exceeding 500 volts per second, to each specimen length of wire. The potential was applied for a period of 60 seconds between the center conductor of the wire and mercury in which the wire was immersed. If evidence of leakage or breakdown was observed, the voltage at which this occurred was recorded. At the conclusion of the test, each wire specimen was carefully examined for evidence of arcing or breakdown. This test was run in accordance with MIL-STD-202B, Method 301.

Test Equipment Used:

<u>Manufacturer</u>	<u>Model</u>	<u>Accuracy</u>	<u>Date Calibrated</u>
Associated Research, Inc.	422	1% of full scale	Sept. 4, 1962

CAPACITANCE AND DISSIPATION FACTOR

Test Procedure: The capacitance and dissipation factor of each specimen length of wire was measured with an impedance bridge. A test potential at 1000 cps was applied between the center conductor of the specimen wire as one electrode, and mercury in which the wire was immersed as a second electrode. The values of capacitance and dissipation factor were read directly from the bridge dials; capacitance was tabulated as picofarads per foot of wire. This test was run in accordance with MIL-STD-202B, Method 305.



Test Equipment Used:

<u>Manufacturer</u>	<u>Model</u>	<u>Accuracy</u>	<u>Date Calibrated</u>
General Radio	1650A	Capacitance $\pm 1\%$ Dissipation Factor $\pm 5\%$	Sept. 7, 1962

INSULATION RESISTANCE

Test Procedure: The insulation resistance of each specimen length of wire was measured with a megohmmeter which applied a potential of 500 volts D. C. between the center conductor and mercury in which the wire specimen was immersed. The insulation resistance, in megohms, was recorded after an electrification time of 60 seconds had elapsed. This test was run in accordance with MIL-STD-202B, Method 302. A schematic diagram of this test circuit appears in Figure 8.

Test Equipment Used:

<u>Manufacturer</u>	<u>Model</u>	<u>Accuracy</u>	<u>Date Calibrated</u>
General Radio	1862B	+ 3% Low Resistance $\pm 12\%$ High Resistance	Sept. 7, 1962

DIELECTRIC CONSTANT

The dielectric constant of each specimen length of wire was calculated from data obtained during capacitance measurements, and from measurement of the wire configuration. The method of computation was as described in paragraph 4.4.3.1 of Specification MIL-W-16878D "Wire, Electrical, Insulated, High Temperature;" as follows:

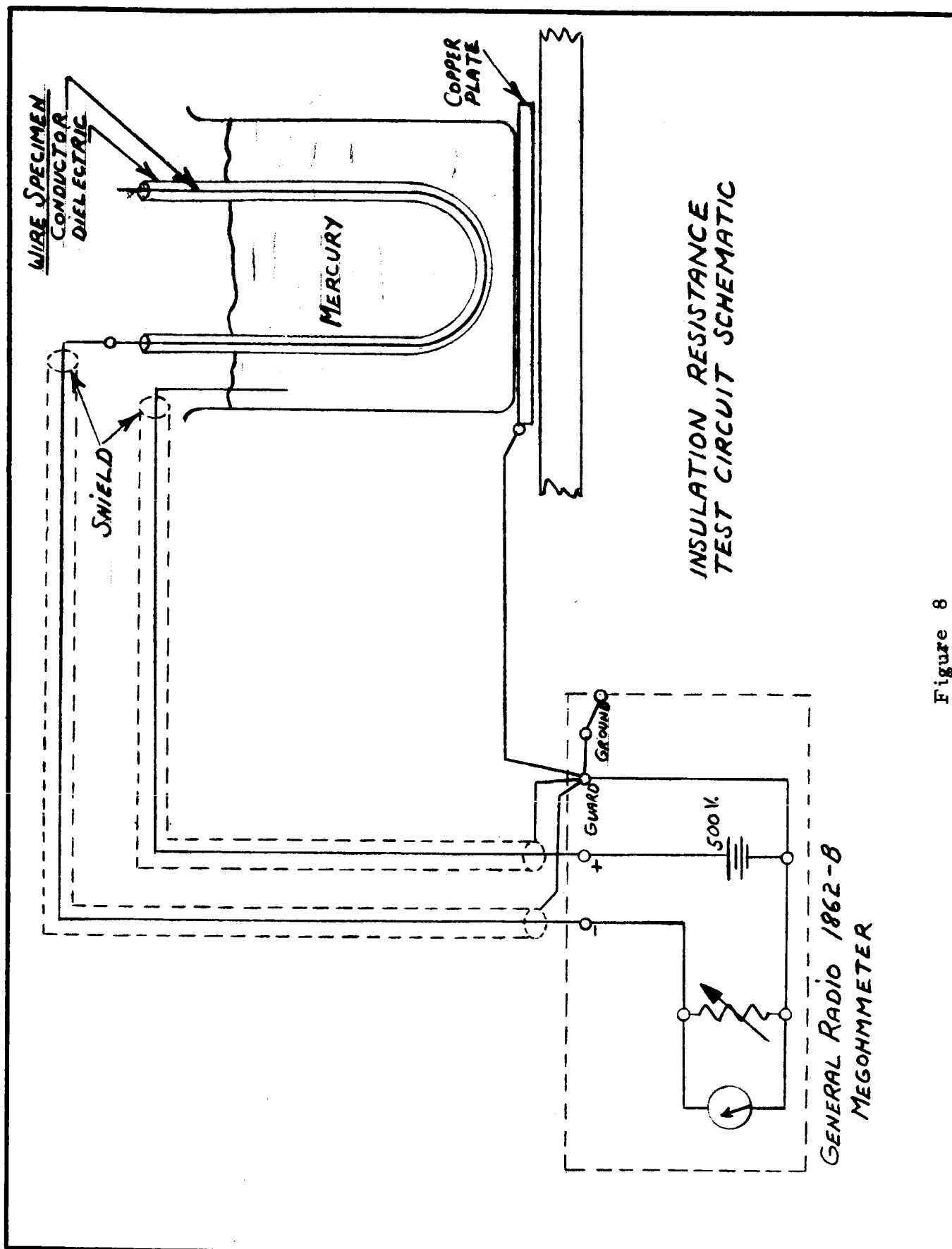
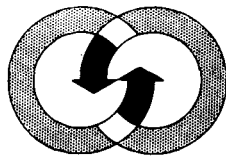


Figure 8



$$K = 136C \log_{10} \frac{D}{d}$$

where

K = Dielectric constant

C = Capacitance of specimen in microfarads
per 1000 feet

D = Average outside diameter over dielectric

d = Average diameter of conductor

VOLUME RESISTIVITY

The volume resistivity of each specimen length of wire was calculated from data obtained during insulation resistance measurements, and from measurement of the wire configuration. The method of computation was as described in paragraph nine of ASTM Standard Test Method D257-61 "Electrical Resistance of Insulating Materials" as follows:

$$\rho = \frac{(D_1 + D_2) L}{2 (D_2 - D_1)} R$$

where

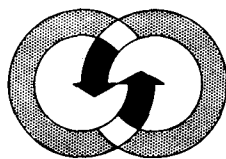
ρ = Volume Resistivity

R = Insulation Resistance in ohms

D_1 = Average diameter of conductor

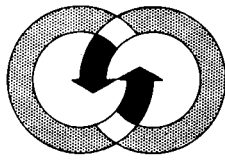
D_2 = Average outside diameter over dielectric

L = Length of wire immersed in mercury



The following assumptions were made:

1. Volume resistance is, in this instance, numerically equal to insulation resistance. This is true because the effects of surface resistance are eliminated by the use of mercury as one electrode, entirely covering the exterior surface of the dielectric.
2. End effects are negligible, due to the large ratio of specimen length to dielectric thickness.



II. TEST DATA

Under several sub-headings, the actual numerical data obtained from the environmental testing of insulated wire specimens. In this section no attempt will be made to analyze or interpret the data presented. This is done to allow readers of this report to draw his own conclusions without prejudice. A subsequent section will give the interpretation of the ARDEL CORPORATION, including any irregularities noted during testing.

The preceeding section gives the details concerning the test methods used.

VACUUM THERMAL TESTS

CAPACITANCE

(measured in picofarads/foot)

(Pressure Range was from 5×10^{-6} to 1×10^{-7} torr)

Test Type	Vacuum at + 300°F	Vacuum at +77°F	Vacuum at -103°F	Vacuum at -312°F	Controls
Wire No. 1	78	74	77	77	77
	76				78
Wire No. 2	63	64	64	63	63
	63				63
Wire No. 3	230	234	234	234	233
	219				231
Wire No. 4	56	56	55	56	56
	56				56
Wire No. 5	93	89	93	92	98
	90				93
Wire No. 6	120	127	124	123	125
	127				120
	124				

Table 1

VACUUM THERMAL TESTS

DIELECTRIC CONSTANT

(Pressure Range was from 5×10^{-6} to 1×10^{-7} torr)

<u>Test Type</u>	<u>Vacuum at +300°F</u>	<u>Vacuum at +77°F</u>	<u>Vacuum at -103°F</u>	<u>Vacuum at -312°F</u>	<u>Controls</u>
Wire No. 1	2.57	2.44	2.54	2.54	2.54
	2.51				2.57
Wire No. 2	1.91	1.94	1.94	1.91	1.91
	1.91				1.91
Wire No. 3	9.79	9.96	9.96	9.96	9.92
	9.32				9.83
Wire No. 4	1.81	1.81	1.78	1.81	1.81
	1.81				1.81
Wire No. 5	2.19	2.17	2.26	2.24	2.39
	2.26				2.26
Wire No. 6	2.14	2.27	2.21	2.20	2.23
	2.27				2.14
	2.21				

Table 2

VACUUM THERMAL TESTS

ABRASION RESISTANCE

Test Type	(measured in inches)				Controls
	(Pressure Range was from 5×10^{-6} to 1×10^{-7} torr)				
	Vacuum at +300°F	Vacuum at +77°F	Vacuum at -103°F	Vacuum at -312°F	
Wire No. 1	43	35	37	46	54
	76				56
Wire No. 2	35	29	24	34	23
	43				
Wire No. 3	55	54	60	67	50
	61				56
Wire No. 4	52	39	45	43	38
	61				57
Wire No. 5	5	4	5	4	3
	5				5
Wire No. 6	18	18	19	18	15
	20				20
	24				

Table 3

VACUUM THERMAL TESTS

DISSIPATION FACTOR

Test Type	(Pressure Range was from 5×10^{-6} to 1×10^{-7} torr)			
	Vacuum at +300°F	Vacuum at +77°F	Vacuum at -103°F	Vacuum at -312°F
Wire No. 1	.004 <.0005	.002	.005	.005
Wire No. 2	<.0005 <.0005	<.0005	<.0005	<.0005
Wire No. 3	<.0005 .020 .016	.022	.022	.026
Wire No. 4	<.0005 <.0005	<.0005	<.0005	<.0005
Wire No. 5	.005 .006	.006	.005	.006
Wire No. 6	<.0005 .001	.001	.002	.002
				Controls
				.010
				.013
				<.0005
				<.0005
				.022
				.022
				<.0005
				.0007
				.006
				.005
				.002
				.002

Table 4

VACUUM THERMAL TESTS

WEIGHT LOSS

Test Type	(% Weight Loss of Total Sample-Conductor + Insulation) (Pressure Range was from 5×10^{-6} to 1×10^{-7} torr)		
	Vacuum at +300°F	Vacuum at +77°F	Vacuum at -103°F Vacuum at -312°F
Wire No. 1	.318 .176	.013	.002 .007
Wire No. 2	.002 (a) .29	.002	0 .001
Wire No. 3	.019 .02	0	0 .002
Wire No. 4	.035 (a) .25	.010	.002 0
Wire No. 5	.022 .04	0	.011 0
Wire No. 6	.072 .07	.105	.013 .008

(a) The thermocouple used to measure temperature was found to be in error and the temperature was lower than 300°F. This figure was included only to indicate that the point where outgassing occurs may be quite abrupt.

Table 5

VACUUM THERMAL TESTS

WEIGHT LOSS

(% Weight Loss of Dielectric Material only)

(Pressure Range was from 5×10^{-6} to 1×10^{-7} torr)

Test Type	Vacuum at			Vacuum at		
	+300°F	+77°F		-103°F		-312°F
Wire No. 1	1.30	.053		.011		.029
	.72					
Wire No. 2	.006	.006		0		.003
	.82					
Wire No. 3	.053	0		0		.005
	.04					
Wire No. 4	.091	.027		.006		0
	.66					
Wire No. 5	.107	0		.053		0
	.22					
Wire No. 6	.378	.546		.069		.046
	.37					

Table 6

ULTRAVIOLET RADIATION TESTS

CAPACITANCE

(Pressure Range was from 5×10^{-7} to 8×10^{-8} torr)

Test Type	Exposure at +300°F		Exposure at +77°F		Controls	
Wire No. 1	78		79	77	78	
Wire No. 2	64		64	63	63	
Wire No. 3	227		231	233	231	
Wire No. 4	53		54	56	56	
Wire No. 5	(a)		91	98	93	
Wire No. 6	114		122	125	120	

(a) A break in the insulation occurred which exposed bare conductor

Table 7

ULTRAVIOLET RADIATION TESTS

DIELECTRIC CONSTANT

(Pressure Range was from 5×10^{-7} to 8×10^{-8} torr)

Test Type	Exposure at +300°F		Exposure at +77°F		Controls	
Wire No. 1	2.57		2.61		2.54	2.57
Wire No. 2	1.94		1.94		1.91	1.91
Wire No. 3	9.66		9.83		9.92	9.83
Wire No. 4	1.71		1.74		1.81	1.81
Wire No. 5	(a)		2.22		2.39	2.26
Wire No. 6	2.04		2.18		2.23	2.14

(a) A break in the insulation occurred which exposed bare conductor

Table 8

ULTRAVIOLET RADIATION TESTS

ABRASION TESTS

(Pressure Range was from 5×10^{-7} to 8×10^{-8} torr)

Test Type	Exposure at +300°F		Exposure at +77°F		Controls	
Wire No. 1	57		55		54	56
Wire No. 2	41		39		23	
Wire No. 3	59		64		50	56
Wire No. 4	60		66		38	57
Wire No. 5	4		4		3	5
Wire No. 6	20		31		15	20

Table 9

ULTRAVIOLET RADIATION TESTS

DISSIPATION FACTOR

(Pressure Range was from 5×10^{-7} to 8×10^{-8} torr)

Test Type	Exposure at +300°F		Exposure at +77°F		Controls	
Wire No. 1	<.0005		<.0005	.010	.013	
Wire No. 2	<.0005		<.0005	<.0005	<.0005	
Wire No. 3	.020		.022	.022	.022	
Wire No. 4	<.0005		<.0005	<.0005	.0007	
Wire No. 5	(a)		<.0005	.006	.005	
Wire No. 6	.003		<.0005	.002	.002	

(a) A break in the insulation occurred which exposed bare conductor.

Table 10

ULTRAVIOLET RADIATION TESTS

WEIGHT LOSS TESTS

(Pressure Range was from 5×10^{-7} to 8×10^{-8} torr)

Test Type	Exposure at +300°F		Exposure at +77°F	
	% Wt. Loss of Total Sample	% Wt. Loss of Dielectric	% Wt. Loss of Total Sample	% Wt. Loss of Dielectric
Wire No. 1	1.31	5.35	0.36	1.46
Wire No. 2	0.13	0.35	0.05	0.13
Wire No. 3	0.03	0.08	0.02	0.05
Wire No. 4	0.55	1.42	0.01	0.03
Wire No. 5	0.11	0.54	0.10	0.48
Wire No. 6	0.11	0.58	0.10	0.54

Table 11

MINIMUM RADIUS FLEXURE TEST

DIMENSIONAL CHANGE

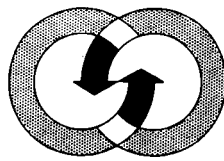
(All test pressures in 10^{-8} torr range)

Test Type	Flexure at +300°F		Flexure at +77°F		Flexure at -103°F		Flexure at -312°F		Average Pre-Test Diameter
	In bend	Out bend	In bend	Out bend	In bend	Out bend	In bend	Out bend	
Wire No. 1	.0085	.0009	.0063	.0003	.0061	.0011	.0078	.0027	0.0535
Wire No. 2	.0012	.0007	.0011	.0008	.0016	.0012	.0020	.0017	0.0515
Wire No. 3	(a)	(a)	.0062	.0001	.0014	0	.0025	0	0.0407
Wire No. 4	.0036	0	.0024	.0001	.0022	.0001	.0027	.0003	0.0505
Wire No. 5	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	0.0151
Wire No. 6	0	0	.0012	0	.0014	.0002	.0022	.0005	0.0433

(a) The conductor fractured during flex while the insulation remained intact.

(b) Both wire and insulation fractured during flex.

Table 12



III. DISCUSSION OF RESULTS

In comparing the test methods with the data tabulation in the preceeding sections, it becomes obvious that data on insulation resistance and dielectric strength have been omitted. The reason for omitting the insulation resistance is that all wires except wire number three had insulation resistance readings of greater than 2×10^{-6} megohms which is the limit of the test instrument. Wire number three had resistance readings of about 2×10^{-5} megohms and this value did not vary significantly between tests.

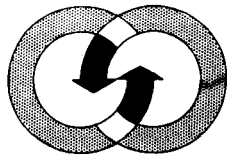
All the wires except wire number five did not breakdown with 5000 volts applied. This is why the dielectric constant was not reported. Wire number five ruptured at approximately 1400 volts and this did not vary significantly for any test.

The leakage which was read on the hypot during measurements of dielectric strength was the result of capacitive reactance and therefore has no significance here.

If 500 picofarads is taken as an average capacitance measurement for a five foot length of wire then the sample calculation below shows that the capacitive reactance is low enough to give an indication of leakage.

$$\text{Capacitive Reactance} = X_c = \frac{1}{2 \pi FC}$$

$$X_c = \frac{1}{(6.28)(60)(500)(10^{-12})} = \underline{5.3} \text{ megohms}$$



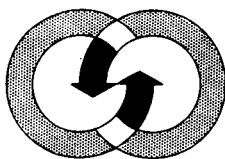
$$I = \frac{E}{R} = \frac{1000}{5.3 \times 10^{-6}} = \underline{.189 \text{ milliamps}}$$

The results of the other tests are discussed in the following sections under the specific test environment.

VACUUM THERMAL TESTS

As is often the case in space environmental testing, many of the changes which occur are very subtle. Although changes of this sort are small and may not seriously effect the performance of the component or material tested, they may alter the entire system in some detrimental manner. The only method available to measure to what extent this may occur is the loss of weight of the sample before and after vacuum exposure. The list of the samples tested in order of those least affected to those of greatest weight loss is 3-5-6-2-4-1. However, in only one case (wire number one) was the material that outgassed from the sample redeposited on the walls of the chamber. This one fact alone should eliminate its consideration for use on a space system. With the exception of this one case, the other samples have a reasonably low weight loss and their use would not be detrimental. The only possible exception is wire number four but additional testing would be required on this sample.

The overall quality of the wires both before and after testing as measured by the dissipation factor has yielded very interesting results. A marked improvement in wire number one seems to indicate that additional



curing or crosslinking may have occurred during vacuum exposure. This may also be extended to say that if this wire were pre-treated in vacuum, its use on space systems may be acceptable. Some slight improvement was also noted on wire number six while wires two and four remained at their same high quality.

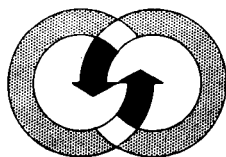
In most instances, a low dielectric constant and/or capacitance is very desirable in a wire sample. All the wires tested with the exception of wire number three are acceptable with wires two and four the most desirable.

Finally, an analysis of abrasion resistance would indicate wires number five, six and possibly two are slightly below par. It must be emphasized, however, that this measurement is the least reliable of all and in the selection of suitable wires, abrasion resistance measurements must be given the least weight.

ULTRA VIOLET RADIATION TESTS

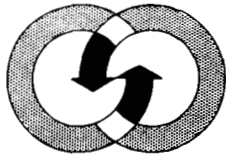
The results of the ultra violet radiation test lead to the same conclusions as the vacuum thermal tests. The degradation, however, was more severe.

Once again wire number one lost the greatest amount of weight and in the higher temperature test, the dielectric material was visibly distorted. Also as in the vacuum thermal tests, the dissipation factor



was reduced, indicating a possible curing or crosslinking of the dielectric. Only a more extensive testing of this wire type, could show if pretreatment by radiation and/or vacuum would allow it to be used on a space vehicle.

Wires number two and four retained their high quality throughout but had a substantial weight loss. This was particularly true of wire four. Wire number three was by far the most superior as regards to weight loss but its high dissipation factor and dielectric constant make its choice questionable.

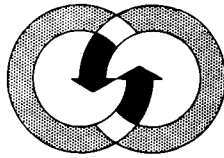


COLD FLOW

One of the objectives of this program was to determine the effect on conductors and conductor insulations due to pressure loading across a point on the conductor, and due to flexure or bending of a conductor across a fixed radius. Specifically, the failure of a conductor due to cold flow and/or deformation must be determined for conductor systems used in a spacecraft.

One of the more critical tests performed under the program was to determine the effect of vacuum on the cold flow of conductor insulation. Several experiments were carried out to test various cold flow apparatus. Basically, the objective was to determine what happened to a conductor in free space when it is subjected to one of the following conditions:

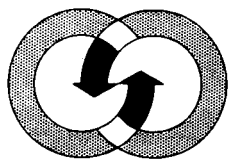
1. The conductors whether single or in a bundle, are tied tightly with a material such as common electrical tying string, thus producing a severe load due to the compression at the perpendicular point of contact between the string and the conductor insulation.
2. A conductor or conductor system which is mounted in a taut condition, and which by improper design or misalignment such as shifting equipment, has become thrust against a sharp edge of some known radius.



3. A conductor which is by necessity laid across a corner or bent over some known radius.

It has been shown in the above tests that at room temperature with loads of as high as 250 pounds per square inch applied perpendicular to a conductor for a period of several weeks will not produce cold flow to the point of catastrophic failure of the conductor for the subject wire insulation. Even when the loading was doubled, no noticeable change was apparent within an approximate three week period. It was decided that it would not be feasible to decrease the radius of the loading wedge, otherwise a cutting action rather than a cold flow would take place.

Basically, three cold flow tests were set up and conducted under this program. The first involved the tying of wires with nylon twine similar to the techniques used in actual surface wiring. It was later decided that it was impossible to predict the loading of the tying of string on the conductor and inasmuch as the conductor and tying string are both flexible, the loading is across an arc rather than at a sharp perpendicular tangential contact. A second problem which persists with this type of test is due to the relaxing of the tying strings with time. A third problem which persists in this type of test is due to the gas load from the tying string itself. Such a gas evolution prohibits the conductor insulation at the point of contact from being exposed to a high vacuum. For the above reasons this test was ruled out as having insufficient accuracies in the criteria for the failure analysis.



A second test which was performed on the conductor involves the loading of a conductor with a perpendicular contact by means of a one pound wedge. The contact edge on the one pound weight was fabricated using a 1/16 inch rod, thus providing a 1/32 inch radius. To provide a flat substrate, the conductor was pulled tight across a glass slide. One end of the conductor was connected to a megohmmeter with the second lead being connected to the one pound wedge. By this technique the changes in conductors insulation could be determined as the wedge cut through the insulation due to cold flow. Inasmuch as teflon presents one of the more outstanding cold flow problems, samples of each of the teflon wires were tested in this manner. It was found however, that the time required for catastrophic failure of the conductor insulation by this technique was a period of possibly several weeks. Before abandoning this test procedure it was decided to check the vacuum to see if the possible acceleration of the cold flow would occur.

The above described apparatus was next setup as shown in Figure 9. The entire test chamber was fabricated from Pyrex glass with the conductor being connected through a glass to metal seal to provide electrical contact. A second glass to metal seal was used to provide electrical contact to the one pound wedge. Again the conductor was laid across a flat glass plate and held tight using a 100 gram weight. A close up of the conductor and wedge is shown in the photograph in Figure 10.



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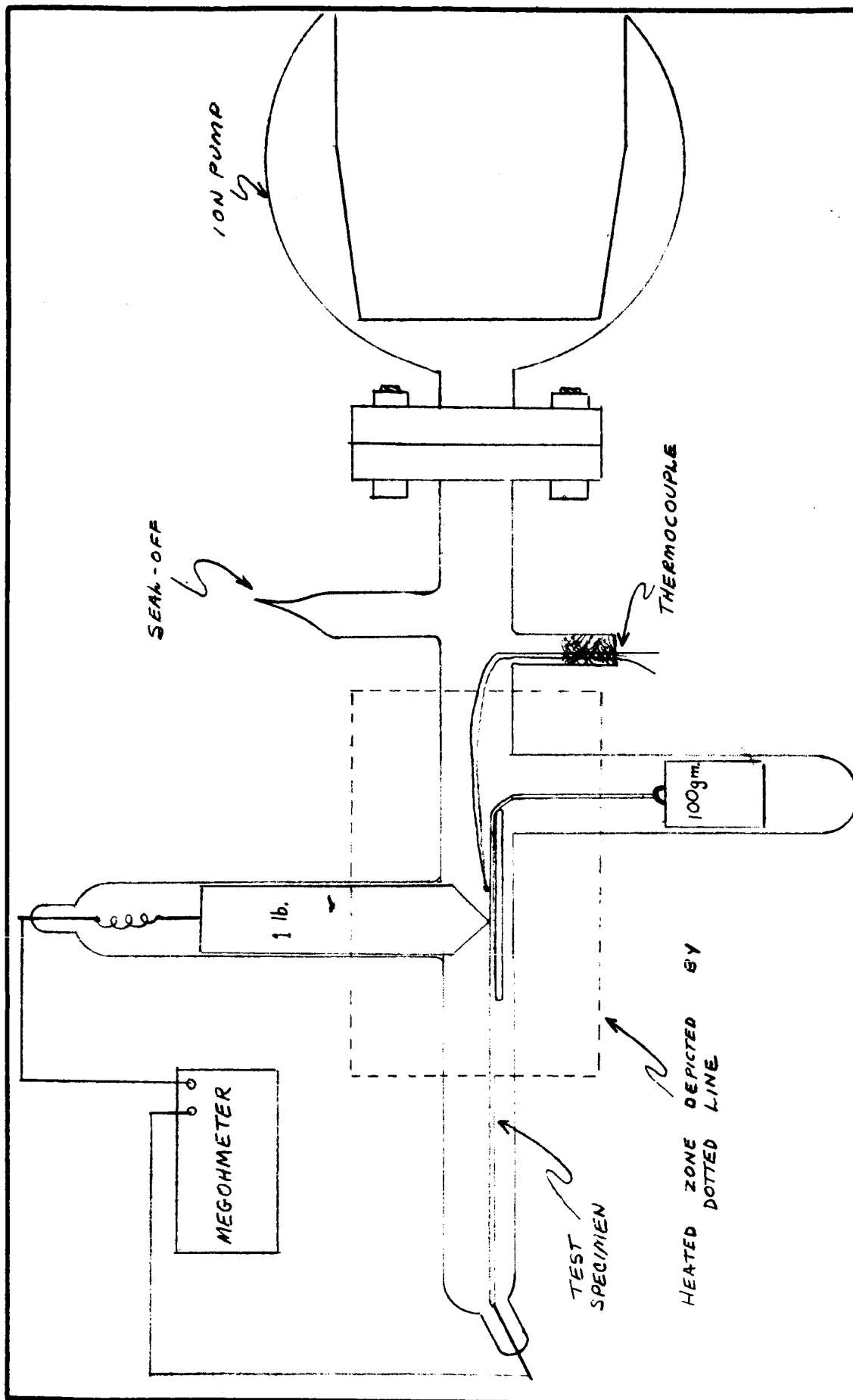


FIGURE 9 COLD FLOW TEST APPARATUS

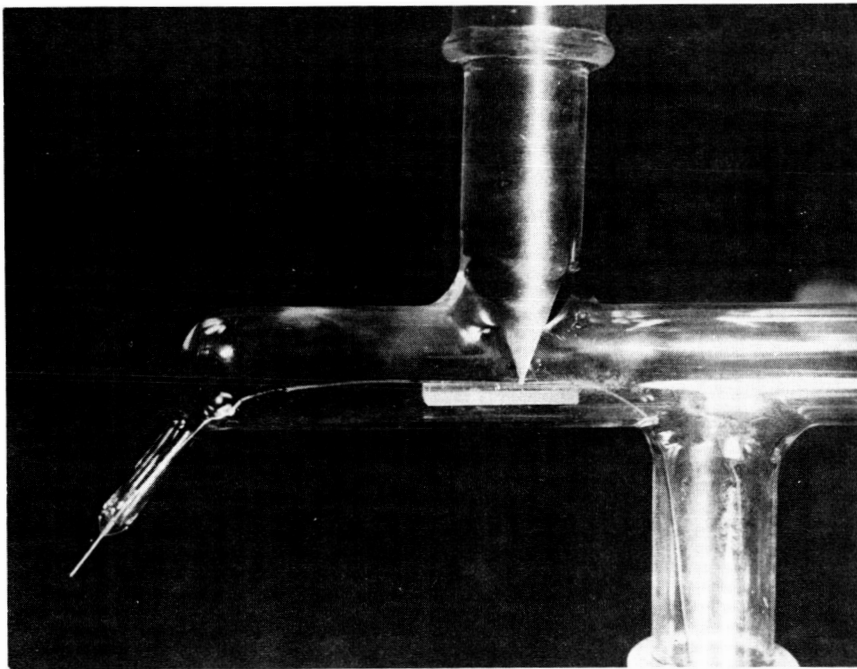
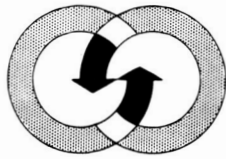
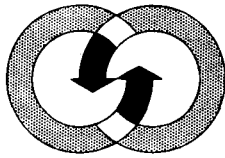


Figure 10

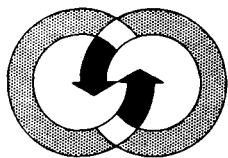
Close Up Of Cold Flow Apparatus



Again there was no detectable change in insulation resistance after a period of up to three weeks. It was decided at this time that only at an elevated temperature would the cold flow become evident within a reasonable period of time. For this reason this test on cold flow was discontinued and a program has been assembled for presentation to the Jet Propulsion Laboratory which would determine the cold flow of various conductors at temperatures of room ambient to as high as 400°F.

MINIMUM RADIUS FLEXURE TEST

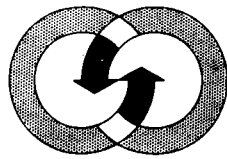
The minimum radius flexure tests which were performed using an apparatus shown in Figure 2 provided a key to a possible method of distinguishing between cold flow and deformation. The test performed on the 6 wires are listed in Table 12. From a brief look at the data it is evident that the most outstanding and demonstrative test results are those obtained at +300°F and -300°F. An approximate length of 7 1/2 inches of each of the 6 conductors was used for the flexure test with a radius of approximately 1/8 inch used to bend the conductors at the given temperatures. Inasmuch as this was the first of a series of tests to develop techniques for screening and qualification of electrical conductors all of the test parameters had not yet been defined. Basically, two related phenomenon were observed. The first was one of cold flow which is commonly seen in materials such as teflon under load. The second one



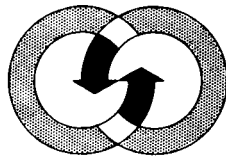
will be classified in this report as deformation. As seen on the electrical conductor system these two terms will be defined as follows. Cold flow is where the insulation has been depressed a measureable amount without noticeable broadening at the conductor loading points. In this type of dimensional change some of the conductor material is absorbed longitudinal rather than across the conductor itself. Deformation on the other hand, consists primarily of crushing of the material without any fluid flow which in turn produces a broadening at the point of contact, and in the plane of the contact surface as well as a depression due to the contacting surface.

In order to eliminate erroneous results due to surface films, occluded gases and moisture, tests were performed in a high vacuum. Pressures in the low 10^{-8} torr region were obtained with this system during each of the conductor tests.

A look at Table 12 shows the dimensional changes which took place on the 6 conductors tested. A comparison between the +300°F and -300°F tests shows that for wire number 1, 2 and 4 a definite cold flow took place at +300°F, while the same conductors at -300°F showed a deformation rather than a cold flow. Wire number 3 displayed a very strange phenomenon in that the conductor only fractured at the elevated temperature (+300°F). The -300°F temperature test showed a definite cold flow in that no out bend or spreading of the conductor was apparent, but rather the entire depression of the material was absorbed longitudinally.



At the uppermost temperature (+300°F) the fracture of the wire occurred at both bend points on the flexure apparatus. The insulation however, did not break nor did it show any obvious changes at either of the contact points. It is assumed from examination of the conductor that the materials were hardened across the joints and thereby fractured. It should also be noted that this was a solid conductor rather than a braided conductor. Wire number 6 showed some deformation at -300°F but at the elevated temperatures the insulation apparently retained sufficient memory to return to its original position before it could be removed from the chamber and measured dimensionally using a micrometer.

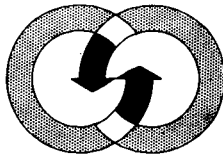


CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The conclusions drawn from the tests performed under this program are by necessity of a qualitative nature. This is due in part to the fact that all of the conductors were not of the same size and type. Specifically, two of the wire samples had solid conductors while the other four utilized braided wire. In addition to the above, one conductor was 28 gauge with the remaining five being 22 gauge wire. It should also be remembered that there are variations due to the use of wrap insulation versus the normal extruded conductor insulations on most of the wires. However, these wires were supplied intentionally so that a comparison could be made between the properties of the solid conductors versus the braided, and to provide some comparison between the extruded insulation and the wrap insulation.

The conclusions drawn by ARDEL CORPORATION are based on a competitive basis. Further qualifications for use would therefore be based on future qualification testing using test parameters which are characteristic of a specific application. Several firm conclusions have been reached based on the above test program which direct future test techniques for qualifications and screening of electrical conductor systems.

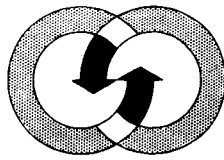


The most significant test parameters for evaluating the test conductors are as follows in order of decreasing importance:

1. Weight Loss
2. Dissipation Factor
3. Dielectric Constant
4. Capacitance
5. Abrasion Resistance

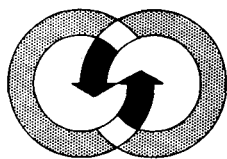
Evaluation of these conductors by insulation resistance and dielectric strength has been eliminated from consideration here for the reasons explained in Section III. With the exception of weight loss, wires number 2 and 4 appear to be the best selection. Wire number 2 displayed between 1/4 and 1/3% weight loss under both vacuum thermal and ultra violet testing. While wire number 4 displayed 2/3% weight loss under vacuum thermal testing losing 1/2% weight loss under ultra violet radiation. The increased weight loss under the ultra violet is quite significant when it is realized that only a small percentage of the total dielectric material was exposed directly to the ultra violet source. Should an external application be required on a spacecraft, careful consideration should be given to the use of wire number 4 inasmuch as it appears to be quite sensitive to ultra violet degradation.

Categorically, 6, 5 and 3 would be rated next to the above two wires in decreasing order. It is rather difficult to compare the



results obtained on wire number 5 especially with respect to abrasion resistance inasmuch as this is a number 28 conductor and has less dielectric thickness to subject to the test parameters. Wire number 3 being a solid conductor system had one outstanding failure when subjected to flexure testing due to the apparent work hardening and fracture of the conductor at the bend point. It should be pointed out however that the polyvinyl fluoride insulation used on wire number 3 withstood most of the test parameters more than adequately. For this reason, this type of insulation system may be considered for space application but should probably be evaluated in a hyper space environment using a braided conductor system.

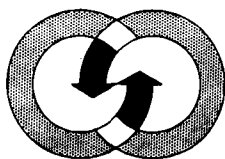
Wire number one has been eliminated from candidacy due to two outstanding limitations. When subjected to vacuum thermal testing, wire number 1 had the greatest weight loss of the 6 candidate samples. Also, the materials which outgassed from this sample deposited on the vacuum chamber, thus, producing a rather dense opaque film which would have very deleterious effects on optical systems on actual spacecraft. When wire number 1 was subjected to minimum flexure testing, it had the greatest cold flow and deformation of the 6 wires tested. When subjected to ultra violet irradiation in high vacuum at +300°F a visible distortion and bubbling was apparent on the surface of the material.



RECOMMENDATIONS

It is the recommendation of the ARDEL CORPORATION that in future evaluations of conductors in a simulated space environment, that they be of the same gauge and be braided conductors. From the test results under this program as well as the experience of the ARDEL CORPORATION it is recommended that the low temperatures be eliminated from the vacuum thermal testing portion of this program inasmuch as sub-zero temperatures only tend to lower the vapor pressures of the volatile constituents and help retain occluded gases. On the other hand it would be more significant to add another elevated temperature point at approximately 150°F in order to obtain data mid-way between room ambient and the 300°F temperature limit. The upper temperature is perhaps too high for some of the conventional materials especially of the polyolefin variety. Wires such as number 1 (Raychem) could perhaps survive 200 or even 250°F exposures while it failed +300°F.

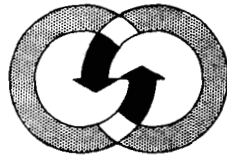
There was an apparent tendency for further cure of the material in wire number 1 (Raychem) due to vacuum thermal or ultra violet irradiation. It may well be beneficial to this conductor system for a recommendation to be made to the manufacturer that this conductor insulation be vacuum temperature cured before exposure to a future qualification test such as the one performed under this program.



The weight loss test of samples 2 and 4 were not entirely reproducible when duplicate samples of each were tested. As pointed out under the vacuum thermal part of the test data section of the report, there was an apparent error in the temperature measurements in both 2 and 4, resulting in their being run at a temperature below 300°F. The results however, are indicative that apparently a sharp break occurred in the weight loss curve for each of these two materials. If 250°F is a more realistic temperature for a space application each of these two wires should be retested at that temperature.

If a comparative evaluation is to be made on conductors for application in a simulated space environment using a cold flow phenomenon as one of the test parameters, an expanded program will undoubtedly be required. Such a program is currently being prepared by ARDEL CORPORATION for submission to Jet Propulsion Laboratory. The subject program would involve the determination of the time to catastrophic failure of a conductor due to cold flow under a given load in vacuum at temperatures from room ambient to as high as 400°F. Thus, a curve could be plotted for each of the conductors which would show the knee or break in the curve at the point where an accelerated cold flow began to take place due to the temperature rise.

The state of the art of abrasion resistance testing will have to be advanced considerably before tests will be available to provide



accuracies and reproducibilities which will permit detection of changes due to the vacuum thermal and ultra violet exposure of the conductor insulation. The standard Janco Abrasion Tester does not permit abrasion tests with accuracies greater than 10%. Perhaps a finer sanding tape may be obtained which will increase the above abrasion distance in inches to permit 1% accuracies and reproducibilities to be obtained.